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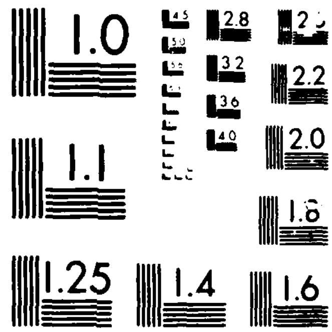
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FOREIGN TECHNOLOGY DIVISION

MATERIAL WITH ANISOTROPIC PROPERTIES FOR MAGNETIC SHIELDING PURPOSES

by

H. Schmid

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MATERIAL WITH ANISOTROPIC PROPERTIES FOR MAGNETIC SHIELDING PURPOSES

Dipl.-Eng. Hans Schmid, Zürich (Switzerland)
has been named as inventor
Albiswerk Zürich A. G., Zürich (Switzerland)

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from 29 April 1944

Patent application announced on 20 November 1952

Patent grant announced on 18 June 1953

The priority of the application in Switzerland
of 30 April 1943 is claimed

When stray magnetic fields are screened by a shielding can or several nested cans the material to be used for the cans plays a decisive role in the shielding effect as well as in the additional losses and the influence on the inductance. The primary question here is the formation of this material from the point of view of the shielding effect, i.e., the formation of a material which is to be used in shielding cans and is especially suited to the achievement of high shielding effects, with respect to static fields as well as dynamic fields.

In magnetic shielding it is necessary to differentiate between static and dynamic screening, a distinction which is also of particular significance for the materials question. While the first type of screening is essentially a problem of potential, the second is understood to be that screening which results in opposing fields induced by eddy-current formation. Only static screening occurs which a permeable material is used with static fields, whereas only dynamic screening is present when a nonpermeable, but electrically conducting, material, such as copper, is employed. If a permeable material is used with dynamic fields, the screening somehow always develops from a static and a dynamic component because of simultaneously permeable and electrically conductive properties. The use of isotropic permeable material or of isotropic nonpermeable, but good electrically conducting material to construct individual shielding cans is known.

The basic difficulty encountered in the screening of magnetic fields is rooted in the fact that there is no completely permeable material ($\mu=\infty$). This is especially true for static screening; but it holds as well for dynamic screening, where, moreover, it is possible in principle to have the formation of eddy fields which counteract the desired shielding effect. Since not only the technical requirements for the shielding effect, but also the requirements for an economical design, are primary considerations in practical shielding, and since it is precisely because of this that the use of several nested shielding cans has not been able to find its way into wide practice, owing to awkward configuration and complicated manufacture, efforts in recent years have primarily aimed at developing and employing materials with the greatest possible permeability. High-grade magnetic alloys such as Permalloy also have rather high production costs, however, and furthermore often exhibit undesirable instability properties when subjected to mechanical and thermal effects. Moreover, the raw material components of such highly permeable alloys are occasionally hard to obtain, so the question of an effective shielding material substitute is of great interest from this point of view as well.

In the present invention the construction of shielding cans no longer utilizes a perdominantly isotropic material, but rather a material with basically anisotropic properties which is particularly suited to the shielding effect. This material with anisotropic properties, i.e., a material which exhibits very different properties in different directions, is of interest for the problem at hand primarily because of the behavior of the permeability and the conductivity, whereas the dielectric properties are less significant for magnetic shielding purposes.

The concept of using such material with anistropic properties to obtain high shielding effects rests on the following considerations: the screening of magnetic fields, using examples related exclusively to the screening medium of the shielding cans, is based on the following: the stray fields are kept away from the shielded zone by the screening medium. They are collected in the static field by the screening medium and carried around the shielded zone. In the dynamic field eddy fields which should compensate for the stray fields form in the screening medium. Both cases involve, on the one hand, intensity effects and, on the other hand, directional effects: the intensity effects are governed by the moderate mass of material; primarily the magnitude of permeability in the static case; and the magnitude of electric conductivity in the dynamic case. The directional effects are essentially determined by the shape of the can. When isotropic material is used, therefore, the shielding effect with this type of stray field is established by size of the scalar material constants with respect to permeability and electric conductivity and by the geometric configuration. While retaining the two principles, highest possible intensity effect of material (high permeability μ, high conductivity x) and influence of geometric shape of shielding cans, which explain what was hitherto known, the remarks above make it evident that, without going into details of design, the shielding capability of the screening medium is significantly improved by providing the material itself with directional effects of the proper kind or by making the screening medium from a material with these properties. From the standpoint of the magnetic shielding effect, such a material, whose properties for the most part are no longer described by an individual scalar, but perhaps instead by a tensor, should meet the following requirements, if possible:

1. The material should be made so that in one direction it exhibits a low permeability, but in the direction perpendicular to the first a relatively high permeability, so that a field occurring in the material is preferentially turned in this direction. This is of particular interest for static behavior.

2. The material should be made so that in one direction it promotes as much as possible the formation of eddy fields, but in the direction perpendicular to the first it suppresses them as much as possible. But then in this direction, because of the suppression of eddy fields, the ratios are reduced to the static, so that in this direction also the first requirement must be satisfied if possible. This second requirement is of interest primarily in the area of dynamic fields.

The material with which the two requirements can be satisfied is one with specific anisotropic properties. For a more detailed explanation let the following definitions first be stated: In an anisotropic material or generally also in a material with anisotropic properties, it is known that the material properties are described by a symmetrical tensor. The material equations are

a) in an anisotropic dielectric

$$\mathfrak{D} = \hat{\beta}\,\mathfrak{E}, \tag{1}$$

where $\mathfrak{D}$ indicates the displacement vector, $\mathfrak{E}$ the electric-field vector, and $\hat{\beta}$ the (absolute) dielectric material tensor;

b) in an anisotropic magnet

$$\mathfrak{B} = \hat{\gamma}\,\mathfrak{H}, \tag{2}$$

where $\mathfrak{B}$ indicates the induction vector, $\mathfrak{H}$ the magnetic-field vector, and $\hat{\gamma}$ the (absolute) magnetic material tensor.

c) in an anisotropic electric conductor

$$\mathfrak{G} = \hat{\varkappa}\,\mathfrak{E}_{,,} \tag{3}$$

where $\mathfrak{G}$ indicates the current-density vector, $\mathfrak{E}$, the electric conductor field strength, and $\hat{x}$ the conductivity tensor.

The material to be discussed requires all three equations (1) to (3) for its description. For magnetic shielding purposes, however, equations (3) and especially (2) are most important. The facts which are of more interest below are elucidated only by equations (2); for equations (3) and (1) exactly the same holds. As is known, an equation like (2) belongs to the linear vector functions. The symmetrical tensor $\hat{\gamma}$ is completely determined by the six elements γ_{11}, γ_{12}, γ_{13}, γ_{22}, γ_{23}, and γ_{33}. Equation (2) can be presented with the aid of the so-called tensor ellipsoid, whose equation is:

$$\begin{aligned}\gamma_{11}\mathfrak{H}_1^2 + \gamma_{22}\mathfrak{H}_2^2 + \gamma_{33}\mathfrak{H}_3^2 + 2\gamma_{12}\mathfrak{H}_1\mathfrak{H}_2 \\ + 2\gamma_{13}\mathfrak{H}_1\mathfrak{H}_3 + 2\gamma_{23}\mathfrak{H}_2\mathfrak{H}_3 = \varphi = \text{const.}\end{aligned} \quad (4)$$

The indices 1, 2, and 3 refer to any orthogonal coordinate triad. Now equation (4) can always be reduced by a primary-axis transformation to a form

$$\gamma_1\mathfrak{H}_1^2 + \gamma_2\mathfrak{H}_2^2 + \gamma_3\mathfrak{H}_3^2 = \varphi = \text{const.} \quad (5)$$

The three primary axes of the permeability tensor ellipsoid then coincide at every point with the coordinate triad, and γ_1, γ_2, and γ_3 are accordingly called the primary permeability coefficients. If equations (1) and (3) are included at the same time, then a brief discussion of the tensor ellipsoid and the primary axis values (not to be confused with the axial lengths of the ellipsoid) follows.

As used in the invention, a material is characterized by a construction for achieving high magnetic shielding effects of shielding cans such that it consists of at least two planar elements of this thickness Δ in close succession, as shown in Fig. 1, which cannot be divided any further into elements of the same kind, whereby the properties of the elements with respect to permeability, dielectric, and electric conductivity are, firstly, essentially the same in the plane of the elements, and, secondly, are subject through the thickness Δ to at least one pronounced external fluctuation. According to its behavior, such a material is characterized with the aid of anisotropy, whereby the one primary-axis value of the material tensors results from the material properties in the directions transverse with respect to the elements, and the other two primary values result from the material properties in two directions at right angles in the plane of the elements. In this sense the present material is even more precisely formulated, to the effect that the material properties are repeated from element to element, so that the tensor ellipsoids belonging to the material tensors are ellipsoids of revolution whose axes of rotation are perpendicular to the elements.

For a more detailed explanation, let several examples based on Fig. 2 to Fig. 4 be shown.

1st Example

Let the permeability along the plane of the elements be essentially constant and vary it transversely with reqpect to the element, in approximate correspondence to the period of a trigonometric function, as shown in Fig. 2. The same then also holds for the electric conductivity and the dielectric. A certain fluctuation in density is therefore present in these material properties.

2nd Example

The element consists of a permeable and a dielectric layer, as shown in Fig. 3. In the plane of the elements the electric and magnetic properties are basically the same; transversely with respect to the element they undergo a strong fluctuation, i.e., they jump from the values of layer 1 to the values of layer 2.

3rd Example

The element differs from that of the 2nd example only because the dielectric layer is replaced by a nonpermeable but good electrically conducting layer.

4th Example

The element consists of a permeable layer 1, a nonpermeable but good electrically conducting layer 2, and two relatively thin, poor electrically conducting layers 3 and 4, which isolate the electrically conducting layers 1 and 2 from each other, as shown in Fig. 4.

It is possible to give further examples of materials which differ in the internal structure of the elements or in the arrangement of the elements. This merely results in the desired deviation from each other of the values of the tensor ellipsoids in the directions transverse with respect to the elements or, of less interest in the proposed application, in their planar directions.

It is furthermore quite clear that the only element which can be described as actually planar is that which cannot be further subdivided into elements still exhibiting essentially the required properties. The planar element is thus the characteristic basic element of this material in terms of its synthesis as well as its analysis.

It is also readily apparent that a material (Type I), such as illustrated by example 4 (Fig. 4) and characterized by the fact that the element is constructed of at least one permeable layer, at least one nonpermeable, good electrically conducting layer, and at least one nonpermeable, poor electrically conducting layer, with these last insulating the metal layers from each other, fully satisfies both stated requirements. This is because the permeability is relatively high in the directions of the planes of the elements and relatively low in the directions perpendicular to the elements. This corresponds to the first requirement for the present. But the second requirement is also satisfied, because in the planes of the elements, with the direction of flow transverse with respect to the elements, for formation of eddy currents is encouraged, while in the directions perpendicular to this, i.e., transverse with respect to the elements, with flow in the direction of the plane of the elements, eddy-current formation is largely suppressed. In the case of the latter direction of flow the ratios are thereby reduced to the static, but at the same time the first requirement again is also satisfied, especially if a proper ratio is established between permeable and nonpermeable element components from case to case. The material described is of interest primarily in the dynamic range, especially in the power-line frequency range, where static and dynamic requirements often must be considered at the same time.

For a material (Type II) which is characterized by the fact that the element is constructed of at least one permeable and at least one nonpermeable, poor electrically conducting layer, which primarily concerns the second example but also the first example to some extent, the same considerations generally apply. A fundamental difference exists to the extent that in the directions of the planes of the elements, with the direction of flow perpendicular to them, the formation of eddy currents is not encouraged, because of the relatively poor conductivity. The second requirement thus is only partly satisfied, so that this material is of interest primarily for the static range of applications.

For a material (Type III) which is characterized by the fact that the element is constructed of at least one permeable and at least one nonpermeable, good electrically conducting layer, that which was said for the first material discussed likewise generally applies. The essential difference consists in the fact that in the directions transverse with respect to the elements, with flow in the direction of the plane of the elements, the formation of eddy currents is greatly encouraged. This deviation from the second requirement considerably restricts the use of this material in the dynamic range.

A material of the kinds named can be obtained in the rolling of iron, for example, where different permeabilities are produced by the rolling process transversely and in the direction of rolling. Furthermore, there are known to be crystals which have the characteristic described. Also, such material can be manufactured by electrolytic processes in which magnetic and nonmagnetic layers are alternately deposited. The same thing can be accomplished as well by vapor deposition, spraying, etc. However, the materials so produced have the drawback, among others, of belonging to Type II or above all to Type III, with their applicability correspondingly reduced. The material with anisotropic properties which in the invention is outstandingly suited to achieving high shielding effects can also be produced in such a way that, by means of appropriate plates, sheets, foils, etc., the individual elements and the elements combined are joined together with the aid of a binding agent by bonding or pressing. The binding agent can at the same time be used here as insulating layers, with the latter naturally being kept as thin as possible, or the plates, sheets, foils, etc. can be held together mechanically, perhaps by rivets or rabbets, with the last layer, for example, continuously beaded and the whole pressed together, or by hinged joints or partial or full caps. Depending on the possibility of working with or without cutting, and depending on the shaping of the air gap, the one or the other mecahnical joining is appropriate in the construction and use of shielding cans. Often it is advantageous to use copper-plated, copper-sprayed, or copper-clad sheet iron even from the very beginning of both the bonding and pressing process and the mechanical process. Copper can also be replaced by another good metal conductor. In addition, the sheets treated in this way can be given an insulating coating, likewise from the very beginning. Finally, welding and soldering may also be mentioned as further possible joining methods.

A further possible production method consists in sequentially pressing powdered layers together.

Finally, it is advantageous to subject the finished material to permeability annealing through heat treatment.

The advantage of materials with anisotropic properties which are used in the invention to achieve high shielding effects lies in the fact that excellent shielding effects are achieved by using less permeable, more readily available substances as well.

Patent Claims:

1. Material with anisotropic properties, characterized by a construction for achieving high magnetic shielding effects by shielding cans, such that it consists of at least two planar elements in close succession and of thickness Δ, which cannot be divided any further into elements of the same kind, and the properties of the elements with respect to permeability, dielectric, and electric conductivity, firstly, are essentially the same in the plane of the elements, secondly, undergo at least one pronounced extremal fluctuation through the thickness Δ, and thirdly, are repeated from element to element so that, corresponding to the anisotropic behavior, the tensor ellipsoids belonging to the material tensors are ellipsoids of revolution whose axes of rotation are perpendicular to the elements.

2. Material per Claim 1, characterized by the fact that the element is constructed of at least one permeable layer, at least one nonpermeable, good electrically conducting layer, and at least one nonpermeable, poor electrically conducting layer.

3. Material per Claim 2, characterized by the fact that the poor electrically conducting layer consists of an insulating material, is relatively thin, and is arranged so that it insulates the element's metallic layers and the elements from each other.

4. Material per Claim 1, characterized by the fact that the element is constructed of at least one permeable layer and at least one nonpermeable, poor electrically conducting layer.

5. Material per Claim 1, characterized by the fact that the element consists of at least one permeable layer and at least one nonpermeable, good electrically conducting layer.

6. Material per Claim 1, characterized by the fact that the magnitude of the tensor ellipsoids varies in the direction transverse with respect to the elements.

7. Material per Claim 1, characterized by the fact that iron sheets provided with a copper layer are components of the element.

8. Material per Claim 7, characterized by the fact that the sheets are coated.

9. Material per Claim 1, characterized by the fact that the element's individual metallic components and the elements combined are held together by a binding agent.

10. Material per Claim 1, characterized by the fact that the elements' individual layers and the elements combined are held together mechanically.

11. Material per Claim 1, characterized by the fact that powdered layers are sequentially pressed together.

12. Material per Claim 1, characterized by the fact that it has undergone permeability annealing.

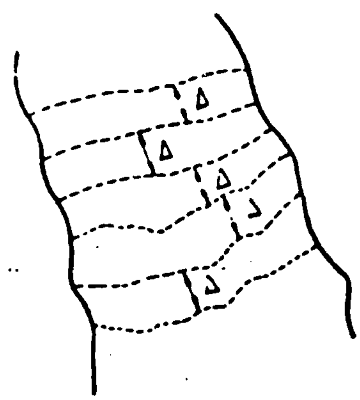


Fig. 1.

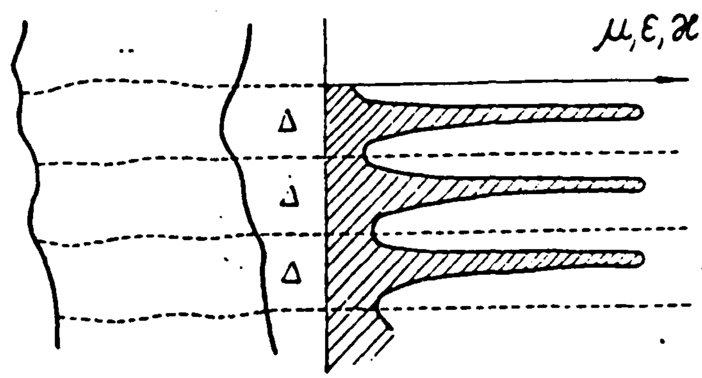
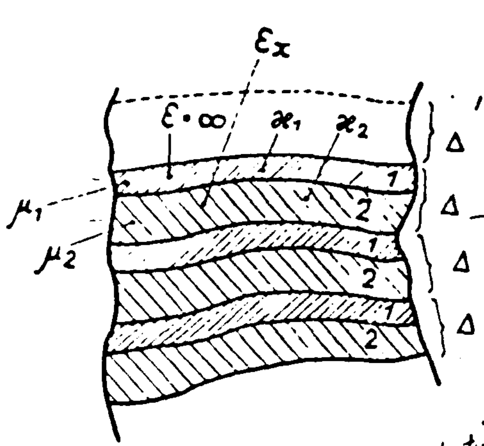
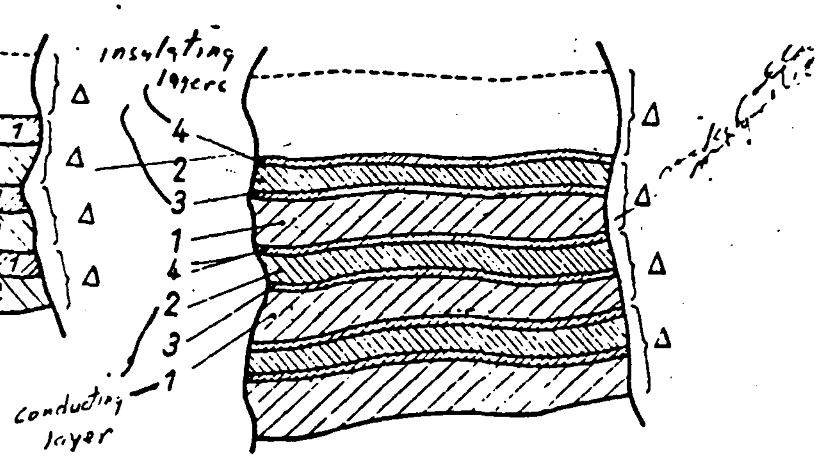


Fig. 2.



ε_x
$\varepsilon = \infty$
$\varkappa_1$
$\varkappa_2$
μ_1
μ_2
1
2
Δ

Fig. 3.



insulating layers
conducting layer
1
2
3
4
Δ

Fig. 4.

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